

W/Z +jet results from the Tevatron

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Selected quantum chromodynamics (QCD) measurements performed at the Fermilab Run II Tevatron $p\bar{p}$ collider running at $\sqrt{s} = 1.96$ TeV by D0 and CDF Collaborations are presented. Events with W/Z +jets productions are used to measure many kinematic distributions allowing extensive tests and tunes of predictions from perturbative QCD at next-to-leading (NLO) order and Monte-Carlo (MC) event generators.

1 Introduction

The D0 and CDF collaborations have extensively studied the W/Z +jet productions since these events are the main background to top-quark, Higgs boson, SUSY and many other new physics production channels. To make discoveries at the Tevatron and the LHC, these processes need to be measured and simulated with a level of accuracy that will be comparable to the significance of the new physics signals.

There are several programs on the market that can simulate hadronic interactions at NLO accuracy, but the processes included in these programs are limited. Matrix element plus parton shower (ME+PS) programs simulate a more comprehensive set of processes, typically at leading-log (LL) or leading order (LO) accuracy, and rely on models to simulate emissions and fragmentation associated with higher order processes. These programs have been employed regularly for background simulation at the Tevatron in recent years, notably in the Higgs searches¹ and the discovery of the production of single top quarks². The Tevatron measurements presented here are compared to predictions by NLO pQCD in MCFM³, BLACKHAT+SHERPA⁴ and ROCKET+MCFM⁵, ME+PS programs ALPGEN⁶ and SHERPA⁷, and PS programs HERWIG⁸ and PYTHIA⁹. The most of measurements have been published^{10,11,12,14,15} or approved as preliminary results^{16,17,18} at the time these proceedings were written. ALPGEN employs the MLM algorithm to ensure jets originating from the matrix element and the parton shower are not double counted. SHERPA is a CKKW-inspired model which uses a re-weighting of the matrix elements to achieve the same appropriate jet configurations. A detailed description of these programs can be found in¹⁹.

In this paper we review some of the recent Tevatron results on the W/Z +jet and W/Z +heavy flavor jet productions.

1.1 W/Z +jet production

Both collaborations have extensively studied the W/Z +jet productions with Z and W decaying via electron and muon decay modes. The leptonic decay of the Z/W provides a clean signal for reconstruction of the events, and small background contamination. The test of pQCD is

made by comparing the measurements to NLO pQCD predictions. The W/Z + jets final states also make up a major background of many new physics searches at both the Tevatron and LHC. Therefore, these data measurements unfolded to the particle level are useful for tuning LO simulation programs which are heavily relied upon to model background processes.

Fig. 1 shows the inclusive cross section for Z/γ^* +jets production measured by CDF¹⁶ as a function of leading and 3rd jet p_T (jets are ordered in descending p_T) in $Z+\geq 1$ jet and in $Z+\geq 3$ jet events. Also shown are dijet invariant mass and azimuthal angle between the two leading jets in $Z+\geq 2$ jet events. The measurements are in agreement with NLO pQCD predictions (BLACKHAT+SHERPA and MCFM) within theoretical scale uncertainties which are about 25%, obtained by variation of the default scale by a factor 2.

D0 measured jet p_T inclusive cross sections of $W + n$ -jet production for jet multiplicities $n = 1 - 4$ ¹¹. The measurements are compared to the NLO predictions for $n = 1 - 3$ and to LO predictions for $n = 4$. The measured cross sections are generally found to agree with the NLO calculation although certain regions of phase space are identified where the calculations could be improved.

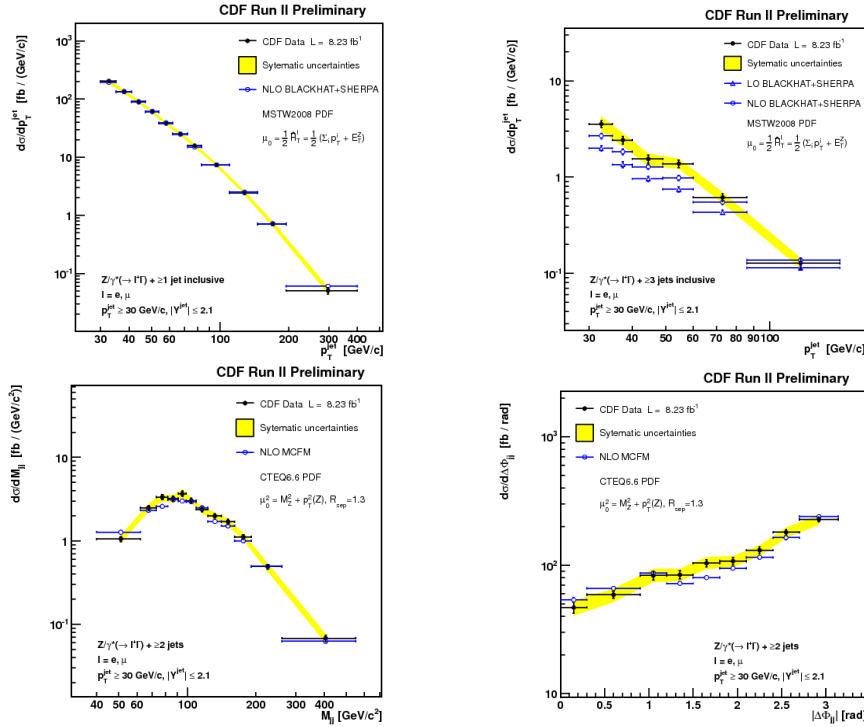


Figure 1: Two top plots show measured inclusive cross section for Z/γ^* +jets production as a function of leading jet p_T in $Z+\geq 1$ jet events (top left) and 3rd jet p_T in $Z+\geq 3$ jet events (top right) compared to NLO pQCD predictions using BLACKHAT+SHERPA. Two bottom plots show measured cross section as a function of dijet invariant mass (bottom left) and azimuthal angle between two jets (bottom right) in $Z+\geq 2$ jet events; results are compared to NLO pQCD predictions using MCFM.

1.2 W/Z +heavy flavor jet production

D0 recently published the measured cross section ratio $\sigma(Z+b)/\sigma(Z+\text{jet}) = 0.0193 \pm 0.0022(\text{stat}) \pm 0.0015(\text{syst})$ for events with jet $p_T > 20$ GeV and $|\eta| < 2.5$ ¹². This most precise measurement of the $Z + b$ fraction is consistent with the NLO theory prediction, 0.0192 ± 0.0022 , done with MCFM, renormalization and factorization scales set at m_Z , and the CDF result $0.0208 \pm 0.0033(\text{stat}) \pm 0.0034(\text{syst})$ ¹³. The CDF collaboration measured the cross section of $W + b$ -jet production $\sigma(W + b) \cdot Br(W \rightarrow l\nu) = 2.74 \pm 0.27(\text{stat}) \pm 0.42(\text{syst})$ pb with jet

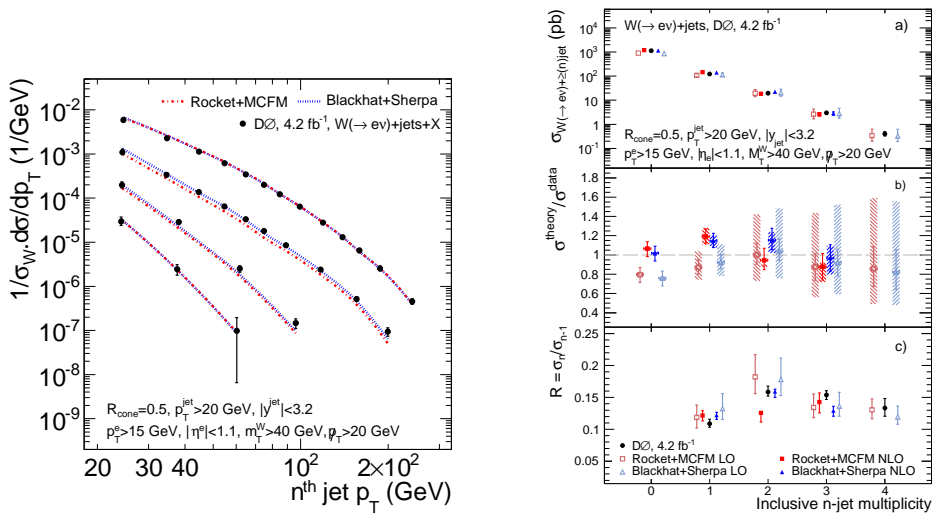


Figure 2: Left: measured $W + n$ jet differential cross section as a function of jet p_T for $n = 1 - 4$, normalized to the inclusive $W \rightarrow e\nu$ cross section. The $W + 1$ jet inclusive spectra are shown by the top curve, the $W + 4$ jet inclusive spectra by the bottom curve. The measurements are compared to the fixed-order NLO predictions for $n = 1 - 3$ and to LO predictions for $n = 4$. Right: (a) total inclusive n -jet cross sections σ_n as a function of n , (b) the ratio of the theory predictions to the measurements, and (c) σ_n/σ_{n-1} ratios for data, Blackhat+Sherpa and Rocket+MCFM. The hashed areas represent the theoretical uncertainty arising from the choice of renormalization and factorization scale.

$p_T > 20$ GeV, $|\eta| < 2.0$ and $l = e, \mu$. The measurement significantly exceeds the NLO prediction 1.2 ± 0.14 pb. The fit results for the b -jet fractions for both the measurements are shown in Fig. 3.

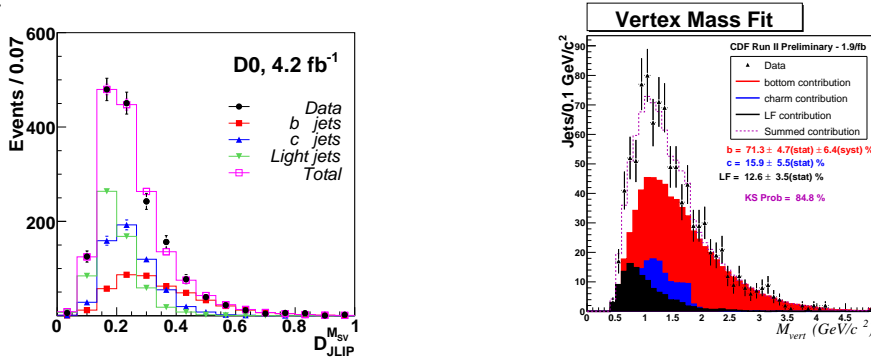


Figure 3: Left (DØ): the distributions of the b , c , light jets and data over the b -jet discriminant; MC templates are weighted by the fractions found from the fit to data. Right (CDF): the secondary vertex mass fit for the tagged jets in the selected sample.

The CDF collaboration has also measured differential cross section of $Z + b$ -jet production versus b -jet p_T and η ¹⁸. Results are shown in Fig. 4. The following cross sections ratio have been also measured, $\sigma(Z + b)/\sigma(Z) = 0.293 \pm 0.030(\text{stat}) \pm 0.036(\text{syst})\%$ and $\sigma(Z + b)/\sigma(Z + jet) = 2.31 \pm 0.23(\text{stat}) \pm 0.32(\text{syst})\%$.

Both experiments measured $W + c$ production cross section using the soft lepton tagging technique^{14,17}. The DØ collaboration measured ratio $\sigma(W + c)/\sigma(W + jet)$ and found it to be $0.074 \pm 0.019(\text{stat})_{-0.014}^{+0.012}(\text{syst})\%$, what is higher than ALPGEN+PYTHIA predictions 0.044 ± 0.003 . The CDF collaboration measured total cross section (electron and muon channels combined) and found $\sigma(W + c) \times Br(W \rightarrow l\nu, l = e, \mu) = 13.3_{-2.9}^{+3.3}$ pb what is in agreement with pQCD NLO predictions 11.3 ± 2.2 pb.

Summary

Several differential cross sections of $W/Z + jet + X$ events measured with the DØ and CDF detectors have been presented. The data are generally consistent with predictions from NLO

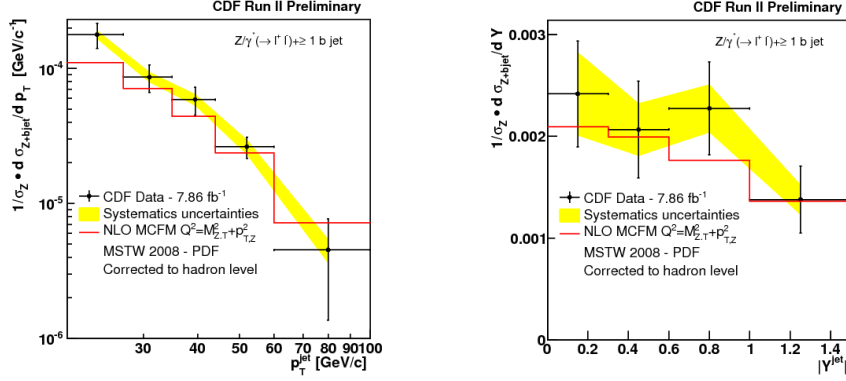


Figure 4: Differential cross section of $Z + b$ production as a function of b -jet p_T (left) and rapidity (right).

pQCD, although some LO programs can also reproduce the shape of the data, sometimes better than NLO, due either to their inclusion of higher parton multiplicity matrix elements than can be currently included in a fixed order pQCD calculation, or an optimized tune of MC. These data should be useful for continued tuning of these and other MC programs used at the Tevatron and LHC experiments.

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